



## **Measuring R at the Upgraded Tevatron\***

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# MEASURING R AT THE UPGRADED TEVATRON

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## Abstract

Future runs at the Tevatron Collider are expected to achieve integrated luminosities of 100 pb<sup>-1</sup> for Phase I (1000 pb<sup>-1</sup> for Phase II-III). With these luminosities we expect to see 6000 (60,000) Z<sup>0</sup> bosons produced after cuts and project that the ratio R will be measured with a total precision of 2.3% (1.2%).

## Definition of R

The ratio

$$R = \frac{\sigma(\bar{p}p \rightarrow W^{\pm} \rightarrow \ell^{\pm}\nu_{\ell})}{\sigma(\bar{p}p \rightarrow Z^0 \rightarrow \ell^+\ell^-)}$$

is the relative rate in  $\bar{p}p$  colliders of W production and decay into a leptonic species to Z<sup>0</sup> production and decay into the same leptonic species.

R can be written as a product of two factors<sup>1)</sup>

$$R = R_{\Gamma} \cdot R_{\sigma}$$

Where R<sub>Γ</sub> is the ratio of branching ratios, and R<sub>σ</sub> is the ratio of cross sections:

$$R_{\Gamma} = \frac{\Gamma(W^{\pm} \rightarrow \ell^{\pm}\nu_{\ell})/\Gamma(W)}{\Gamma(Z^0 \rightarrow \ell^+\ell^-)/\Gamma(Z^0)} \quad R_{\sigma} = \frac{\sigma(W^{\pm})}{\sigma(Z^0)}$$

R<sub>Γ</sub> can be written as a function of sin<sup>2</sup>θ<sub>w</sub>, M<sub>Z</sub>, and M<sub>t</sub><sup>1)</sup> as determined by standard model couplings<sup>2)</sup>. The functional form has three distinct regions corresponding to possible mass ranges of the top quark. The low range is where the top quark is light enough for the Z decay mode Z<sup>0</sup> → t $\bar{t}$ , that is when 2M<sub>t</sub> < M<sub>Z</sub>. The intermediate region is where the top quark is too heavy for the above decay but the

decay  $W \rightarrow t \bar{b}$  is still kinematically possible since  $M_t < M_W - M_b$ . The high mass region is where the top is too heavy to be a  $W$  decay product  $M_t > M_W - M_b$ .

Recent results from CDF, SLAC and LEP put the value of the top mass, using a search for standard model predicted decay modes well within the high mass region where the value of  $R$  is independent of  $M_t$ .

As  $R_\sigma$  is a function of  $\sin^2\theta_w$  and proton structure functions, two difficulties arise in calculating the value of  $R_\sigma$ . First, the structure functions depend upon the measurement of the ratio  $F_n^2/F_p^2$  which for the  $x$ -values reached at the Tevatron ( $x = 0.001$  to  $0.01$ ) has been measured by only two experiments. Second, while the  $Q^2$  dependence of these measurements is small, the structure functions must be evolved up to  $Q^2 = M_W^2$ . While the method of evolution is well defined, experimental data exists only at low  $Q^2$  where the structure functions have corrections that are not well understood.

### What $R$ Will Tell Us

Recent results from CDF, and precision measurements of the  $Z$  width from SLAC and LEP will determine the number of neutrino generations and constrain any anomalous physics that would broaden  $\Gamma(Z^0 \rightarrow e^+e^-)$ .

Taking the above value of the  $Z^0$  width as input the measurement of  $R$  becomes a measurement of  $\Gamma(W^\pm \rightarrow e^\pm \nu_e)$ , which now is a function of  $\Gamma(Z^0)$ ,  $\sin^2\theta_w$  and structure functions.

The width of the  $W$  is a fundamental parameter in the standard model (S.M.) and is important to measure in its own right. Any possible observed deviations from the S.M. predicted value could be an indication of new physics that enters in by adding new decay channels to the  $W$  boson. One possibility that meets this criterion is a light top that decays into a charged Higgs,  $W \rightarrow t + \bar{b}$ ;  $t \rightarrow H^+ + b$ . Another possibility is a charged Higgs isotriplet ( $H^+$ ,  $H^0$ ,  $H^-$ ) with masses  $M_{H^\pm} + M_{H^0} < M_W$ ;  $M_{H^\pm} > M_{Z^0}/2$ .

While these examples may not be considered very probable they do illustrate the wide range of different kinds of processes to which the  $W$  width is sensitive.

### Measurement of $R$

The projected uncertainties from a measurement of  $R$  are listed in Table I. The  $5 \text{ pb}^{-1}$  column is based on preliminary CDF electron data. The  $100 \text{ pb}^{-1}$  and  $1000 \text{ pb}^{-1}$  columns are what we project for D0 using either electron or muon data. For simplicity in this analysis we have taken the uncertainties in the muon data as similar to those of electron data, and tried to project how the uncertainties in the electron data could be decreased with more data.

The statistical uncertainty is dominated by the size of the  $Z^0$  sample. In projecting the  $Z^0$  sample we have simply multiplied the  $5 \text{ pb}^{-1}$  value by the increased flux.

The backgrounds for  $W^\pm$  (and  $Z^0$ ) are the number of non- $W$  (non- $Z^0$ ) events that are identified as  $W$  ( $Z^0$ ) events. As the event sample increases the various distributions used to study the backgrounds will have smaller statistical uncertainties which should lead to smaller uncertainties in the quoted systematics.

The efficiency is how well we identify a  $W$  or a  $Z^0$  event. Again we project that the systematic uncertainty in this correction will be improved with more statistics.

The acceptance is a convolution of the acceptances for  $W$  and  $Z^0$  with the cross sections for their production:

$$\frac{\sigma(W) \cdot \text{Acceptance}(W)}{\sigma(Z^0) \cdot \text{Acceptance}(Z^0)}$$

The acceptance calculation for  $W$  or  $Z^0$  production involves a Monte Carlo using a production model for  $W$  or  $Z^0$  which includes structure functions, the decay into leptonic channels and, lastly, the detection characteristics of the detector for those leptons. Any changes in the production model will change the energy or position of the lepton in the detector, either of which could change the acceptance for that lepton. The largest part of the uncertainties in the acceptance come from uncertainties in the structure functions.

The standard model uncertainty is any uncertainty in the input parameters, such as  $M_{Z^0}$ ,  $\Gamma(Z^0)$ ,  $\sin^2\theta_W$  and so on, in using the measured  $R$  to extract  $\Gamma_W$ , the width of the  $W$ .

## Conclusions

The measurement of  $R$  in future collider runs at the Tevatron can be used to measure the width of the  $W$ , a basic S.M. parameter. The uncertainties in measuring  $R$  can be reduced with increased flux to be sensitive to the uncertainties in structure functions and S.M. parameters. With independent measurements of the structure functions the  $R$  measurement can be used as a consistency check on the S.M. which is sensitive to many types of possible new physics.

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**Table I.**  
**Projected Uncertainties in R Measurement \***

Category	5 pb <sup>-1</sup>	100 pb <sup>-1</sup>	1000 pb <sup>-1</sup>
Z <sup>0</sup> Statistics	300 events 6.0 %	6000 events 1.3 %	60,000 events 0.4 %
W Background	0.5 %	0.5 %	0.5 %
Z <sup>0</sup> Background	1.0 to 3.0 %	1.0 %	0.5 %
Efficiency	3.0 %	1.0 %	≤ 0.5 %
Acceptance	2.0 %	1.0 %	0.5 %
S.M. Input Parameters	0.5 %	≤ 0.5 %	≤ 0.5 %
<b>Total</b>	<b>8.0 %</b>	<b>2.3 %</b>	<b>1.2 %</b>

\* The 5 pb<sup>-1</sup> numbers are based on preliminary CDF electron data.

## References

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